# PATENT SPECIFICATION

**279,149**

Application Date: July 7, 1926. No. 17,063/26.

Complete Left: May 6, 1927.

Complete Accepted: Oct. 7, 1927.

## PROVISIONAL SPECIFICATION.

## Improved Rolls for Rolling Metals.

We, FRANCIS DAVID CORBIN, of 181, Tyrfran, Llanelly, in the County of Carmarthen, a British subject, THE LLANELLY FOUNDRY AND ENGINEERING COMPANY, LIMITED, of Sandy, Llanelly, in the County of Carmarthen, and RICHARD NEVILL AND COMPANY, LIMITED, Wern Iron Works, Llanelly, in the County of Carmarthen, both British companies, do hereby declare the nature of this invention to be as follows:—

This invention relates to the manufacture of rolls for rolling metals.

The object of this invention is to provide metal rolls having higher physical properties than the chilled iron rolls at present in general use.

According to the present invention we provide a process of making rolls in case-hardened alloy steels whereby the case-hardened portion of the rolls may have a hard "martensitic" or "troostitic" structure and the remaining portion a soft "pearlitic" or allied structure, both structures being obtained with the same slow rate of cooling from high temperatures. To this end, certain elements, such, for example, as nickel or manganese, are introduced into the steel, and which, in the presence of sufficient carbon, tend to retain the metal in the hard martensitic or troostitic condition, after a rate of cooling so slow that a steel of the same carbon content, but without said elements, would have passed into the relatively soft pearlitic condition. In these alloys the effect of carbon on this tendency, for a given proportion of the special element or elements, is cumulative, that is, a suitably chosen alloy will be pearlitic, soft and tough, with a low percentage of carbon, but troostitic or martensitic, and very hard, with a high percentage of carbon on being cooled slowly in both cases.

Having selected the constituents for the steel alloy which will give, for each individual case, suitable physical characteristics in the core of the roll with a low percentage of carbon, and a suitable hardness on the working face with a high percentage of carbon, we then make the roll of a low carbon content alloy, and adjust the amount of the special element or elements and also the percentage of carbon introduced into the case, as governed by the temperature of case-hardening, so as to give, on slow cooling, a pearlitic core and a martensitic or troostitic case—as may be required, thus attaining maximum hardness for the latter without the necessity for reducing the temperature of the roll from high temperatures in water or other liquid, with all the risks attendant on this procedure.

Of the elements, which may be usefully employed for alloying in the process manganese, vanadium, tungsten, chromium and molybdenum, favour the absorption of carbon by solid steel during case-hardening, while nickel tends to hinder it. Thus if nickel is used one or more of the first mentioned elements should be used with it to counteract this tendency, while this addition of a further special element or elements can generally also, by careful choice, be made to enhance generally the qualities of the resultant alloy. Nickel and chromium, for example form a very suitable combination for many purposes.

By way of example we will describe our process for the making of a roll in a nickel-chrome steel alloy. For hardness without unnecessary brittleness, the case should be at, or slightly above, the eutectoid composition, say, 1.0 per cent. carbon. For normal cooling in air, with 1.0 per cent. carbon, 5.0 per cent. nickel will give a martensitic structure, but with carbon contents below 0.80 per cent.

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the structure will be pearlitic. For a nickel content of 5.0 per cent., 1.0 per cent. of chromium will be sufficient to ensure carbon-absorbing properties, and will give a harder case without unduly increasing brittleness while, further, the structure will not coarsen under heat treatment in the presence of so much nickel This percentage of chromium will not appreciably affect thermal critical points etc., and its presence may be ignored in calculations.

We cast or forge the roll in a steel of the following composition

| Ni | Cr. | C. |
|---|---|---|
| 5.0 | 1.0 | 0.20 (or less). |

The roll is then well annealed at a temperature of approximately 750° C., the $Ac_1$ thermal critical point for this composition being approximately 700° C. Thereafter the roll is allowed to cool to room temperature and then machined, the body being brought to a smooth finish and left say, .015" overall full to final size. After machining, the roll is hardened in a box having removable ends, or other device, to allow of its rapid removal whilst hot.

With a hardening mixture consisting of 60 per cent. oak, or beech, charcoaland 40 per cent. barium carbonate, a temperature of 900° C. will give approximately 1.0 per cent. carbon in the case, the time taken obviously varying with the depth of case required and being easily determined. At the conclusion of the hardening process, the grain-structure is refined by allowing the roll to cool down in its hardening box to below the thermal critical point of the case whereafter it is re-heated to approximately 50° C. above said point. After removal from the furnace, the roll is stripped, and allowed to cool in air. Where an exceptionally tough core is required the refining process may be doubled, that is to say, the roll, after its preliminary cooling from the hardening temperature, may be first reheated up to, and furnace-cooled from just above the critical range of the core, then re-heated up to just above the critical point of the case, and cooled in air.

After cooling, the roll is finally ground to size and polished, the machining allowance given above being sufficient for the removal of any slight decarburised " bark " (that is, the extremely thin skin of metal which is robbed of its carbon by oxidation).

Dated the 7th day of July, 1926.

For the Applicants,
STANLEY, POPPLEWELL & Co.,
Chartered Patent Agents,
88, Chancery Lane, London, W.C. 2.

## COMPLETE SPECIFICATION.

# Improved Rolls for Rolling Metals.

We, FRANCIS DAVID CORBIN, a British subject, of 181, Tyrfran, Llanelly, in the County of Carmarthen, THE LLANELLY FOUNDRY AND ENGINEERING COMPANY, LIMITED, of Sandy, Llanelly, in the County of Carmarthen, and RICHARD NEVILL AND COMPANY, LIMITED, Wern Iron Works, Llanelly, in the County of Carmarthen, both British companies, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to improved rolls for rolling metals.

Quenched rolls have the disadvantage that enormous internal stresses are generated on quenching, while hair-cracks and similar surface flaws are liable to develop in the working surface, these defects causing " spawls " during the working of the roll. In chilled cast iron rolls, which are brittle and have poor mechanical strength throughout, the chilled iron rim or " chill " has a rate of expansion under heat which is twice that of the grey iron core, so that enormous internal stresses are set up on increase of temperature. Great internal stresses are also set up when the roll is cast, owing to the rapid cooling of the roll body, and, moreover, when the chill is worn out it cannot be renewed. A further common disadvantage of quenched and chilled rolls is the difficulty in manufacturing them for rolling complicated sections.

The object of this invention is to obviate these disadvantages and to provide rolls for rolling metals having higher physical properties than the rolls at present in general use and which may be manufactured in complicated shapes.

It has previously been proposed in Specification No. 23,331/04 to manufac-

ture case-hardened articles having martensitic cases and pearlitic cores of chrome-nickel steel without subsequent hardening by quenching, but without further directions, which have not been disclosed, it would not be possible to manufacture in this manner rolls suitable for rolling metals.

In the case of rolls it would be possible, by carbonizing at a temperature which, though suitable for normal case-hardening (including quenching) would be too low for our purpose, to introduce into the case a percentage of carbon less than that necessary to retain the metal in the solid solution condition on slow cooling, and thus a martensitic, troostitic, cementitic or allied structure would not be obtained.

It is necessary, therefore, to so regulate the temperature of carburizing (in accordance with normal case-carburizing practice) that the fully carburized zone shall contain a certain definite proportion of carbon which will bear a calculated relationship with the other constituents of the metal.

The accompanying drawings show the structure obtained on normal slow cooling with various proportions of carbon and of the alloying element used in each case. Thus in the case of nickel steel, Fig. 1, a material containing 5.00% nickel and 0.20% carbon is represented by the point X, and will obviously give a pearlitic structure on slow cooling. Whereas, with 1.00% carbon, the material, is represented by the point Y, and will be martensitic on slow cooling. If however, the carbon is raised above 1.35% the point representing the material will move over the line A C to Z, and the structure will be austenitic. For rolls this must be avoided, and in order to manufacture a satisfactory roll it will be necessary to carburize this material in such a manner that the point representing the fully carburized material will lie between the lines A B and A C i.e., for 5% nickel the carbon must be between approximately 0.80% and 1.35%. In practice it is advisable not to work too near these limits and the carbon should be, say, between 0.95% and 1.2%.

Referring to Fig. 2, a steel containing, for example, 3.5% manganese and a low percentage of carbon, say 0.20% is represented by the point X, and will give a pearlitic structure on slow cooling, whereas with 1.0% carbon the material is represented by the point Y, and will be martensitic on slow cooling. If, however, the carbon is raised above 1.18%, the point representing the material will move over the line A C to Z and the structure will be austenitic. Thus, the percentage of carbon in the carburized zone of a 3.5% manganese steel roll must lie between the points at which the lines A B and A C cut the 3.5% manganese line, i.e. between approximately 0.65% and 1.18%. In practice the figure should be well away from either extreme, and a suitable amount would be approximately 1.0%. The proportion of carbon required in the carburized zone may be ascertained in like manner for any other suitable percentage of manganese.

A steel containing, for example, 0.75% vanadium and 0.20% carbon is represented by the point X, Fig. 3, and will be pearlitic on slow cooling, whereas with any amount of carbon in excess of 0.45% (this being the amount represented by the point at which the line A B cuts the 0.75% vanadium line) the material will be cementitic on slow cooling; that is to say, an appreciable proportion of the carbon will be in the form of free carbide crystals embedded in the otherwise martensitic structure.

Thus, the percentage of carbon in the carburized zone of a 0.75% vanadium steel roll must exceed 0.45%. The point Y represents 1.0% carbon, and, in practice, this would be a convenient figure.

The minimum carbon content for the carburized zone of a vanadium steel roll may be ascertained in a like manner for any other suitable percentage of vanadium.

Similarly in the case of a molybdenum steel roll see Fig. 4, the steel must be carburized so that the carburized zone contains not less than that proportion of carbon indicated by the point at which the line A B cuts the line representing the molybdenum content of the steel being used.

For a 1.25% molybdenum steel, for example, the carburized zone must contain more than 0.82% carbon (in practice 1.00% would be a convenient figure) and the working face thus obtained would be cementitic in structure, as in the case of vanadium steel.

Referring to Fig. 5, in the case of a tungsten steel roll, the steel must be carburized so that the carburized zone contains not less than that proportion of carbon indicated by the point at which the line A B cuts the line representing the tungsten content of the steel being used. For a 4.00% tungsten steel, the carburized zone must contain more than 0.975% carbon. In practice, 1.20% to 1.25% would be a convenient figure and the working face thus obtained would be cementitic in structure.

In the case of chromium, as shown by

Fig. 6, by carburizing an initially soft material it is possible to obtain either a martensitic structure or, if sufficient carbon and chromium be present in the carburized zone, a cementitic structure as defined for vanadium steels. While both structures are—subject to the mechanical properties of the material—suitable for the working faces of rolls, the latter is sometimes preferable where extreme hardness or resistance to the softening action of high working temperatures, or both, are required. Thus a steel containing 7.00% of chromium and 0.20% of carbon is represented by the point X, and will be pearlitic on slow cooling, whereas, when carburized so as to contain more than the amount of carbon represented by the point at which the line C D cuts the 7.00% chromium line, i.e. 1.3%, the steel will be cementitic on slow cooling. In practice, this limit would be appreciably exceeded, and 1.4% would be a suitable figure, this being represented by the point Y.

When two (or even more) alloying elements are present in a steel, it is possible to use the diagram of any one of these. As it is not possible to show three variables (e.g. nickel, chromium, and carbon) and a resultant structure on a plane diagram, it is necessary to ascertain the equivalent value of one of the alloying elements in promoting a hardened structure—whether martensitic or cementitic—as compared with the other. Then, by reducing the percentage actually being used of the one to terms of the other, and adding the figure so obtained to the actual percentage of the other, a joint figure is obtained which is used as the special element (i.e. the upright) co-ordinate on the diagram of the said other element in ascertaining by means of this diagram the amount of carbon which will be required in the carburized zone.

The obtaining of this "equivalent value" of any one element in terms of any other element is a simple mathematical process. For example, in the case of a nickel chromium steel, take any convenient carbon figure, say 0.80% on both nickel and chromium diagrams. By reference to the latter, Figs. 1 and 2, it is seen that 0.80% carbon requires a minimum of 5.0% nickel to obtain a martensitic structure with slow cooling, whereas the chromium diagram shows that 4.2% chromium gives the same result.

As the line A B meets the carbon line at the same point (1.6%) in both diagrams, the nickel/chromium equivalency relationship may be expressed by a simple multiplication factor

i.e. Equivalent in nickel

$$= \text{Chromium}\,\% \times \frac{5.0}{4.2}$$

$$= \text{Chromium}\,\% \times 1.2.$$

Thus, in the case of a steel containing 5.00% nickel and 0.80% chromium, the "nickel equivalent" of the latter element is:—$0.80 \times 1.2 = 0.96\%$. The nickel diagram (Fig. 1) may therefore be used, reading the nickel percentage as $5.00 + 0.96 = 5.96\%$. The minimum carbon content required in the carburized zone would therefore, by consulting the diagram, be 0.67%, but as nickel only tends to produce the austentic structure, 5.00% only must be taken as the co-ordinate in observing the maximum permissible carbon content, i.e. that at which 5.00% nickel line is cut by the line A C. This is 1.35% carbon, and therefore the carburized zone must contain between 0.67% and 1.35% carbon. In practice, 1.00% would be a convenient figure.

According to the present invention, therefore we provide a roll for rolling metals, made in case-hardened alloy steel and having its case-hardened portion of a hard martensitic, troostitic, cementitic or allied structure, and the remaining portion of a soft pearlitic or allied structure, both structures being obtained with the same slow rate of cooling of the roll from high temperatures, the proportion of carbon contained in the fully carburized zone being regulated so that the relative proportions of carbon and of the alloying element or elements are such that for any given percentage of said element or elements the percentage of carbon shall be sufficiently high, on the one hand, to ensure that the carburized zone shall remain in the martensitic, troostitic, cementitic or allied condition even after slow cooling, and, on the other hand, sufficiently low, to ensure that when using nickel or manganese this zone shall not be in the austenitic condition. The regulation of the amount of carbon contained in the fully carburized zone is effected by regulating the temperature of carburizing in accordance with normal case carburizing practice.

Having selected the constituents for the steel alloy which will give, for each individual case, suitable physical characteristics in the core of the roll with a low percentage of carbon, and suitable physical characteristics combined with great hardness on the working face with a high percentage of carbon, we then make the roll of an alloy containing a low percentage of carbon and such amounts of the other constituents as will give, on slow cooling, with this low percentage of carbon, a pearlitic or allied

structure, and with a suitable high percentage of carbon, to be obtained in the case by case-carburizing, a martensitic, troostitic, cementitic or allied structure, as may be required, thus attaining maximum hardness for the case without the necessity for reducing the temperature of the roll from high temperatures in water or other liquid, with all the risks attendant on this procedure.

Examples of suitable amounts of various alloying elements, with the amounts of carbon required in the carburized zone in each case, are :—

| | | | |
|---|---|---|---|
| Nickel | - 5% | Carbon | .9 to 1.25% |
| Chromium | - 7% | ,, | 1.4 % |
| Tungsten - | - 4% | ,, | 1.25% |
| Molybdenum | - 1.25% | ,, | 1.0 % |
| Vanadium | - .75% | ,, | 1.0 % |
| Manganese | - 3.5 % | ,, | .9 to 1.1% |

By the term "allied" as applied to pearlitic structure is meant a structure in which all, or a preponderating proportion, of the carbon present has come out of solid solution during the cooling of the metal, although the cementitic constituent of the pearlite instead of being lamellar in form might be globular or finely diffused. "Allied" as applied to martensitic and troostitic structures indicates a structure in which all, or a preponderating proportion, of the carbon present has remained in solid solution after cooling down to normal air temperatures, and, in the case of a cementitic structure, indicates a structure in which some of the carbon has assumed the form of free particles of carbide embedded in the remainder of the material, wherein all, or a preponderating proportion, of the rest of the carbon has remained in solid solution.

Of the elements which may be usefully employed for alloying in the process, manganese, vanadium, tungsten, chromium and molybdenum, favour the absorption of carbon by solid steel during case-hardening, while nickel tends to hinder it if solid case-hardening cements are used. Thus, if nickel is used in conjunction with a solid cement (that is, the solid carburizing material in which the roll is packed), one or more of the first mentioned elements should be used with it to counteract this tendency, while this addition of a further one or more of the above mentioned elements can generally also by careful choice, be made to enhance the general qualities of the resultant alloy. Nickel and chromium, for example, form a very suitable combination for many purposes.

By way of example, we will describe our process for the making of a roll for cold rolling of metals, in a nickel-chrome steel. For hardness without unnecessary brittleness, the case should be at, or slightly above, the eutectoid composition, say 1.0% carbon. Reference to Fig. 1, shows that approximately 6.0% of nickel will be a suitable amount, since, with 1.0% of carbon, the structure will be martensitic, whereas with a low percentage of carbon, such as 0.20%, the structure will be pearlitic. As mentioned previously, it will be advisable to have a certain amount of chromium in the steel to facilitate the absorption of carbon during case carburizing, and in the case of a roll a nickel/nickel-equivalent-of-chromium ratio of 5:1 will give suitable mechanical properties, while this amount of chromium will be sufficient to ensure ready carbon absorption when using solid case carburizing cements. Bearing in mind the nickel-chromium "equivalency ratio" previously described, a suitable composition would be

Nickel 5.0% Chromium 0.8%

the "nickel equivalent" of this being

$$5.0+(0.8\times 1.2)=5.96\%$$

i.e. approximately 6%.

We, therefore, cast or forge the roll in a steel containing approximately $\frac{\text{Ni}}{5.0\%}\ \frac{\text{Cr.}}{0.80\%}\ \frac{\text{C.}}{0.20\%}$. The roll is then well annealed at a temperature of approximately 750° C., the $Ac_1$ thermal critical point for this composition being approximately 700° C. the roll is then allowed to cool to room temperature and then machined, the body being brought to a smooth finish and left, say, .015" overall full to final size. After machining, the roll is case carburized in a box having removable ends, sides or top, to allow of its rapid removal whilst hot.

With a carburizing mixture consisting of 60 per cent. oak, or beech, charcoal and 40 per cent. barium carbonate, a temperature of 900° C. will give approximately 1.0 per cent. carbon in the case for this composition, the time taken obviously varying with the depth of case required and being easily determined. At the conclusion of the carburizing procedure, the grain structure of the core may be refined by allowing the roll to cool down in its carburizing box to well

below the thermal critical range of the core material, whereafter it is reheated to 840° C., and after being kept at this temperature for 5 hours for a roll 20 inches in diameter and pro rata, the roll in its box is removed from the furnace. On removal from the furnace, the roll is stripped, and allowed to cool in air. Where an exceptionally tough core is required the refining process may be doubled, that is to say, the roll after its preliminary cooling from the case-hardening temperature may be first re-heated up to, and furnace cooled from, above the critical range of the core, then re-heated up to just below the said critical range and cooled in air.

When no grain structure refining procedure is utilized, the roll will be removed from the furnace at the lowest temperature from which air cooling will give the required degree of hardness in the case.

After cooling, the roll is finally ground to size and polished, the machining allowance given above being sufficient for the removal of any slight decarburized "bark" (that is, the extremely thin skin of metal which is robbed of its carbon by oxidation during the final cooling down in air).

It should be noted that when the final cooling of the roll in air is for any reason undesirable, or when either extreme hardness on the working face of the roll is unnecessary or a composition may be used which, with the amount of carbon to be introduced by case-hardening in the particular instance, will be so far removed from the structure-transition range as to ensure that, even on very slow cooling, the case structure will remain in the required hard condition, the final cooling of the roll may take place in the carburizing box either in or out of the furnace and not in air. In this case, the case-hardening material packed around the roll in the carburizing box is not disturbed.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A roll for rolling metals, made in case-hardened alloy steel and having its case-hardened portion of a hard martensitic, troostitic, cementitic or allied structure, and the remaining portion of a soft pearlitic or allied structure, both structures being obtained with the same slow rate of cooling of the roll from high temperatures, the proportion of carbon contained in the fully carburized zone being regulated so that the relative proportions of carbon and of the alloying element or elements are such that for any given percentage of said element or elements, the percentage of carbon shall be sufficiently high, on the one hand, to ensure that the carburized zone shall remain in the martensitic, troostitic, cementitic or allied condition even after slow cooling, and, on the other hand, sufficiently low, to ensure that when using nickel or manganese this zone shall not be in the austenitic condition, substantially as described.

2. A roll as claimed in Claim 1, made in a low carbon content alloy containing one of the elements nickel, chromium, tungsten, molybdenum, vanadium and manganese, the proportion of each element and of carbon required in the carburized zone in each case being approximately as follows:—

| | | | |
|---|---|---|---|
| Nickel | 5% | Carbon | .9 to 1.25% |
| Chromium | 7% | ,, | 1.4 % |
| Tungsten | 4% | ,, | 1.25% |
| Molybdenum | 1.25% | ,, | 1.0 % |
| Vanadium | .75% | ,, | 1.0 % |
| Manganese | 3.5 % | ,, | .9 to 1.1% |

3. A roll for rolling metals, made in alloy steel and containing approximately

| Ni. | Cr. | C. |
|---|---|---|
| 5.0% | 0.80% | 0.20% |

said roll being annealed, allowed to cool and machined to a smooth finish, then case-hardened as claimed in Claim 1 so as to give approximately 1% of carbon in the case, allowed to cool in the case-carburizing box to below the thermal critical range of the core, re-heated to 840° C., removed from the furnace, and allowed to cool, and (if desired) ground and polished.

4. A modification of the roll claimed in Claim 3, having an exceptionally tough core, said roll being re-heated after its preliminary cooling from the case-carburizing temperature, up to, and furnace-cooled from, above the critical range of the core, and then re-heated up to just below the said critical range and cooled.

Dated this 6th day of May, 1927.

For the Applicants,
STANLEY, POPPLEWELL & Co.,
Chartered Patent Agents,
88, Chancery Lane, London, W.C. 2.

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FIG.1.

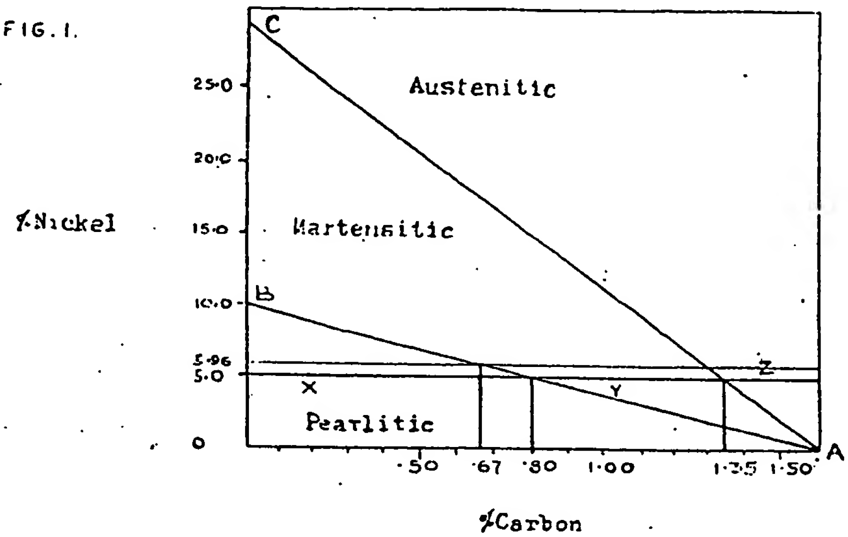



FIG.2.

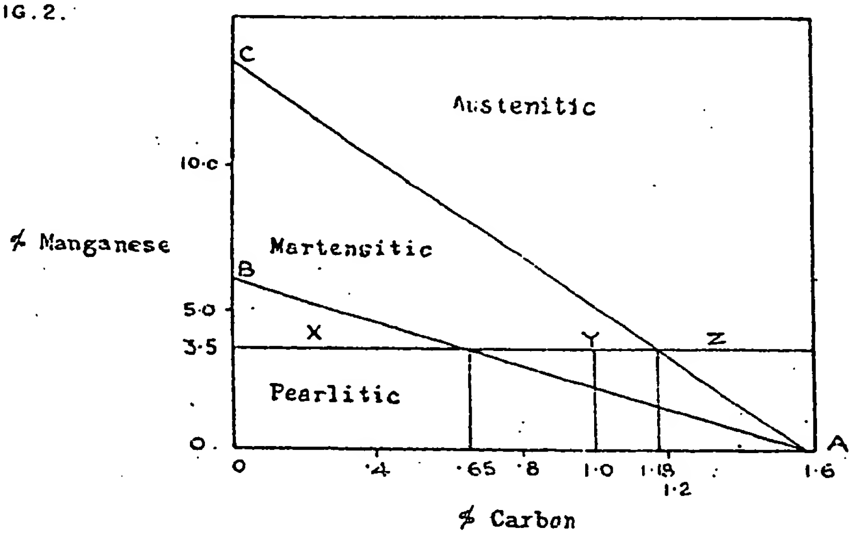



FIG.3.

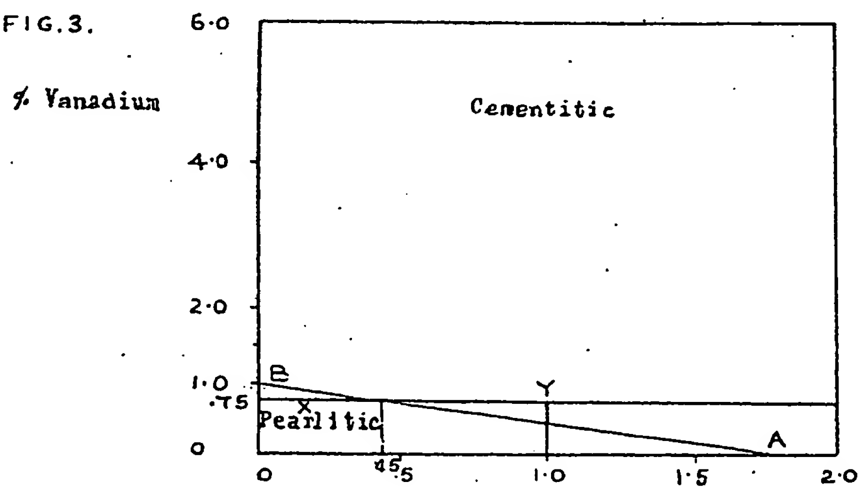



FIG.

% Moly

FIG.

% Tun

FIG

% Chr

FIG. 4.

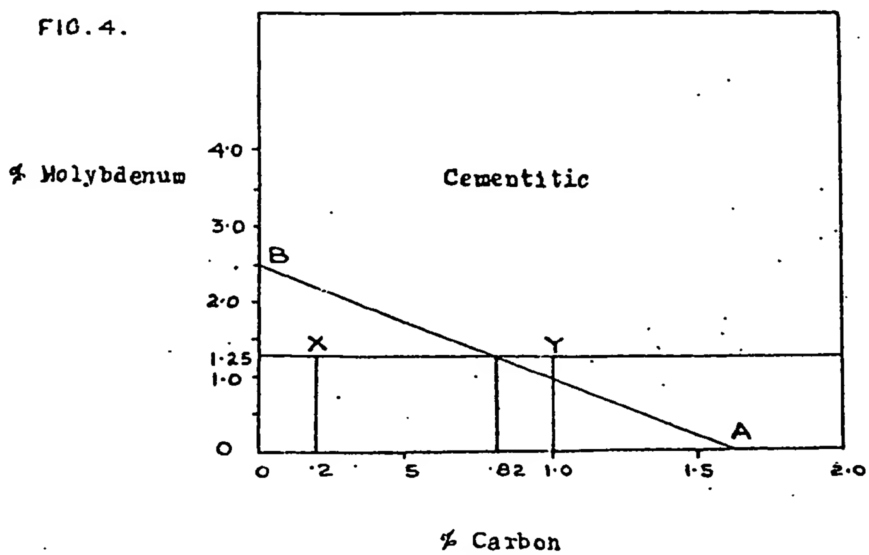



FIG. 5.

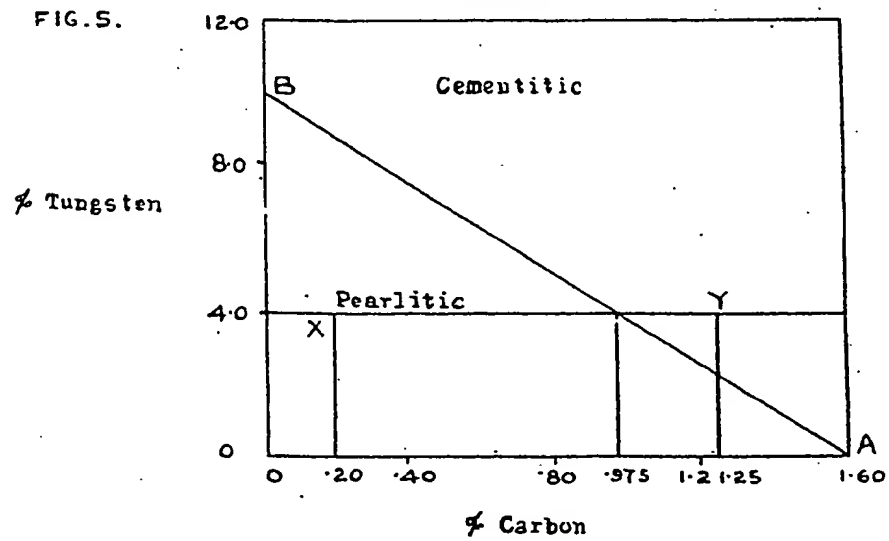
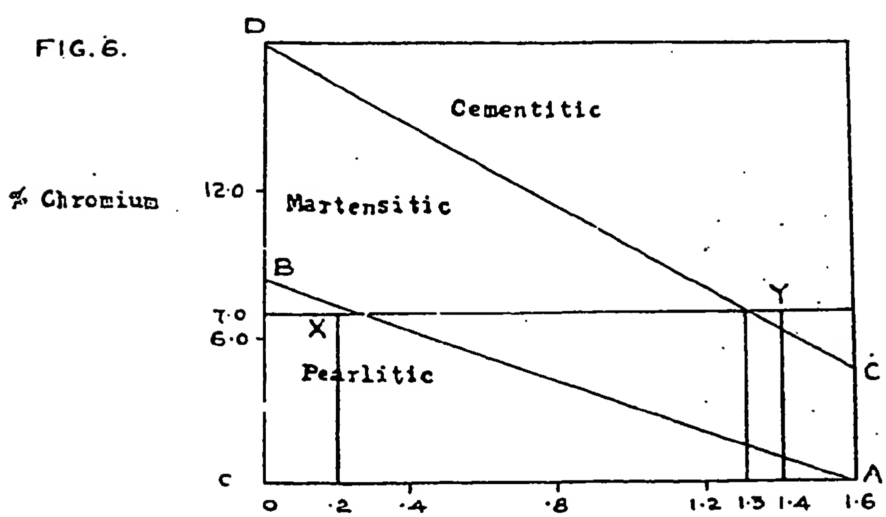



FIG. 6.




A

A
1·6

2·0

FIG. 1.

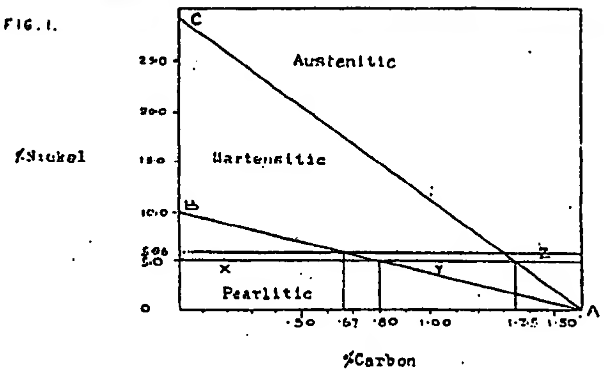



FIG. 2.

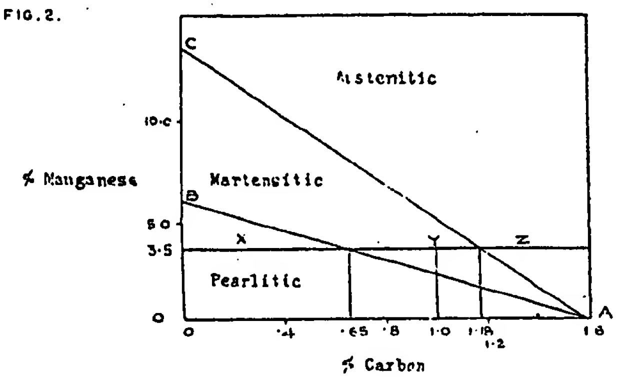



FIG. 3.

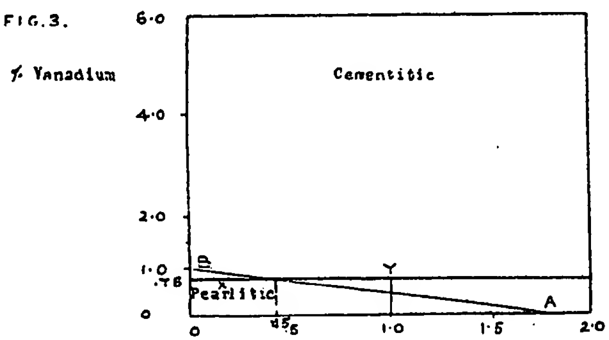



FIG. 4.

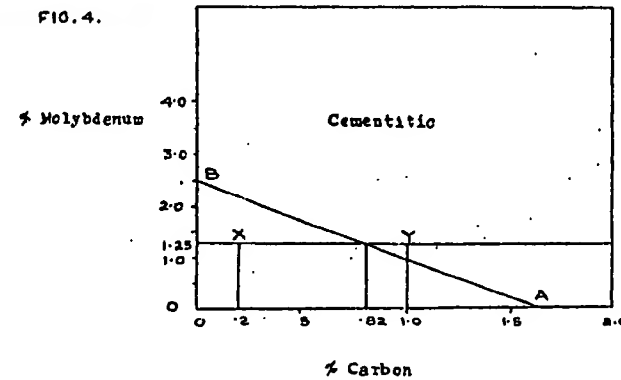



FIG. 5.

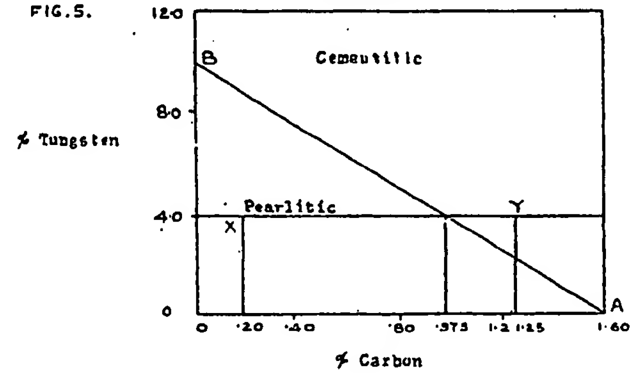
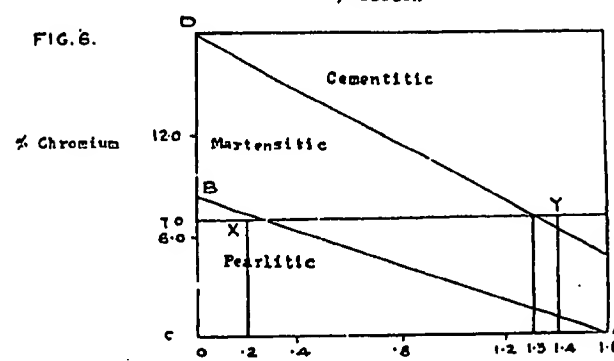



FIG. 6.

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